Hubbard Watershed, Texas
2D Base Level Engineering and Mapping Methods and Results

Texas Water Development Board Contract No. 2101792542, Task Order 1

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1. Introduction

Base Level Engineering (BLE) provides technically credible flood data for various geographies - community, county, watershed and/or state level. BLE data can be shared with Federal, State, local and tribal governments, this data sharing provides stakeholders at all levels the necessary data to make informed decisions to reduce future flood losses. Without the mapping of flood prone areas, there can be a lack of information to effectively communicate flood risk to community officials, citizens, and businesses.

BLE is a riverine hydrologic and hydraulic modeling approach that builds on lessons learned to produce a baseline understanding of flood risk to communities, produced to support the assessment and maintenance of the national flood hazard inventory. Engineering models are created during a BLE assessment, producing information that meets the mapping Standards for Flood Risk Projects (FEMA Policy Memo FP 204-078-1) to produce Zone A (1-percent-annual-chance flood) information. BLE data is intended to represent the base level of investment needed for all flood study efforts FEMA will undertake. The Hubbard watershed BLE documented here was designed to use two-dimensional (2D) modeling techniques with enhancements and calibration to develop products that can be communicated and shared with stakeholders, and transitioned into FEMA regulatory data development workflows.

The intent of BLE is to provide communities technically credible flood hazard information in a cost efficient and timely manner. Additionally, BLE provides communities a chance to review draft modeling information, reflecting the potential changes in risk within their community. Providing additional flood risk datasets, like water surface elevation (WSEL) grids and flood depth grids, delivers alternative information that reinforces the variability of flood risk within a designated floodplain and supports historic community requests for a source to determine a Base Flood Elevation in Zone A areas.

For floodplain management purposes, BLE data may be used as best available information in areas that are designated as Zone A floodplain. It may also be used to regulate development in areas where no Special Flood Hazard Area (SFHA) has been mapped before. Communities may adopt BLE data to support local regulations, which facilitates use of the data in local floodplain management activities, including in the post disaster environment where a need for updated and/or enhanced flood hazard information may be necessary.

BLE provides information to communities who are currently unmapped and provides a digital entry to communities that are currently un-modernized. BLE acts as a measuring tool to allow FEMA to assess the current Zone A inventory identified as unknown or unverified in FEMA's Coordinated Needs Management Strategy (CNMS), which FEMA is required to evaluate once every five years, as described in Title 42 of the Code of Federal Regulations, Chapter III, Section 4101(e). FEMA makes this determination of flood hazard data validity by examining flood study attributes and change characteristics, as specified in the Validation Checklist of the Coordinated Needs Management Strategy (CNMS) Technical Reference. The CNMS Validation Checklist provides a series of critical and secondary checks to determine the validity of flood hazard areas studied by detailed methods (e.g., Zone AE, AH, or AO). While the critical and secondary elements in CNMS provide a comprehensive method of evaluating the validity of Zone AE studies, a cost-effective approach for evaluating Zone A studies has been lacking. Another important goal of the BLE process is scalability of the results, meaning that the model produced during the BLE assessment may be refined to produce a more enhanced model with additional manual correction and on the ground survey. If BLE modeling exists, FEMA will recommend that it be used as the base model for any detailed studies performed in those areas.

BLE practices leverage high-resolution topography that meets or exceeds the United States Geological Survey (USGS) 3-D Elevation Program (3DEP) standards and often applies flood engineering at a large scale as opposed to targeting stream reaches within a watershed. BLE can be conducted at any scale, commonly for larger areas (Hydrologic Unit Code (HUC)-8 watershed) but may be produced at the county or local level too. It is encouraged to do BLE for wider areas in order to build on efficiencies in modeling and ensure cost efficiency. Using current technologies, multiple watersheds or watersheds with large land areas can be analyzed at a more efficient rate to produce water-surface elevations and site-specific hazard data replacing outdated flood studies shown in existing Flood Insurance Rate Maps (FIRMs). All flood prone areas within a watershed will have an engineering model calculating multiple flood recurrence intervals and defining floodplains with elevation grids using high-resolution topography.

Per standard identification SID #84 and #133, BLE will include all recurrence intervals (0.2-percent, 1-percent, 1-percent plus, 1-percent minus, 2-percent, 4-percent, and 10-percent-annual-chance floods). As such, hydrologic and hydraulic analysis should be performed to determine the expected WSELs for each of the seven recurrence intervals previously identified.

The Hubbard watershed 2D BLE project was scoped as described in the Texas Water Development Board (TWDB) Task Order 1 (Contract 2101792542). In an effort to increase and enhance the flood risk products in Texas, the study was contracted through the TWDB's Cooperative Technical Partner (CTP) program to AECOM Technical Services, Inc. This report documents the BLE process, products, and results for this watershed. Figure 1 depicts the Hubbard watershed footprint.

Figure 1: Hubbard Watershed

2. 2D BLE Modeling Inputs and Controls

Section 2 presents fundamental components required to execute a 2D hydraulic engineering analysis for the Hubbard watershed using Hydrologic Engineering Center's River Analysis System (HEC-RAS) version 6.1 (RAS6). Inputs such as elevation data, hydrology from rain-on-grid and inflow hydrographs, and hydraulic analyses and variables are defined herein. RAS6 rain-on-grid utility was applied in the production of the 2D BLE products produced for this watershed.

2.1 Topographic Data

A high resolution Digital Elevation Model (DEM) is a fundamental component for 2D engineering analyses by providing a detailed representation of the surface for hydraulic routing through the model area. As such, DEMs were developed for the Task Order 1 project by leveraging available high resolution gridded elevation data derived from Light Detection and Ranging (LiDAR) collections throughout the States of Texas. Task Order 1 watersheds include Double Mountain Fork Brazos (Hydrologic Unit Code (HUC) 8 No. 12050004), Hubbard (HUC-8 12060105), Lower Clear Fork Brazos (HUC-8 12060104), and Paint (HUC-8 12060103). The 1 meter DEM developed to support the 2D BLE modeling and analysis, within the Hubbard watershed, was executed using the following steps:

1. Available elevation data for the project area were inventoried and collected.
2. Leveraged elevation data were evaluated and prioritized based on source vertical accuracy, year of collection, and resolution.
3. Seamless DEMs were processed using Geographic Information Systems (GIS).
4. Quality was assured using quantitative and qualitative assessment.

Documentation regarding leveraged data including coverage, accuracy, acquisition dates, and source contact/agency are presented in the figures, tables and text within Section 2.1.2. All vertical accuracy specifications were obtained from the metadata or survey reports provided with the leverage datasets. All available metadata, survey reports, and other leverage documentation are included in the FEMA Data Capture Technical Reference compliant submittal content for the Hubbard watershed.

2.1.1 Inventory

An inventory of existing topographic data was conducted for the Hubbard BLE watershed footprint. Figure 2 depicts the datasets identified and leveraged across the project area. FEMA, National Oceanic and Atmospheric Administration (NOAA), USGS, Texas Natural Resources Information System (TNRIS) and other State and Federal agencies were queried to build the inventory with the most current and available data sources.

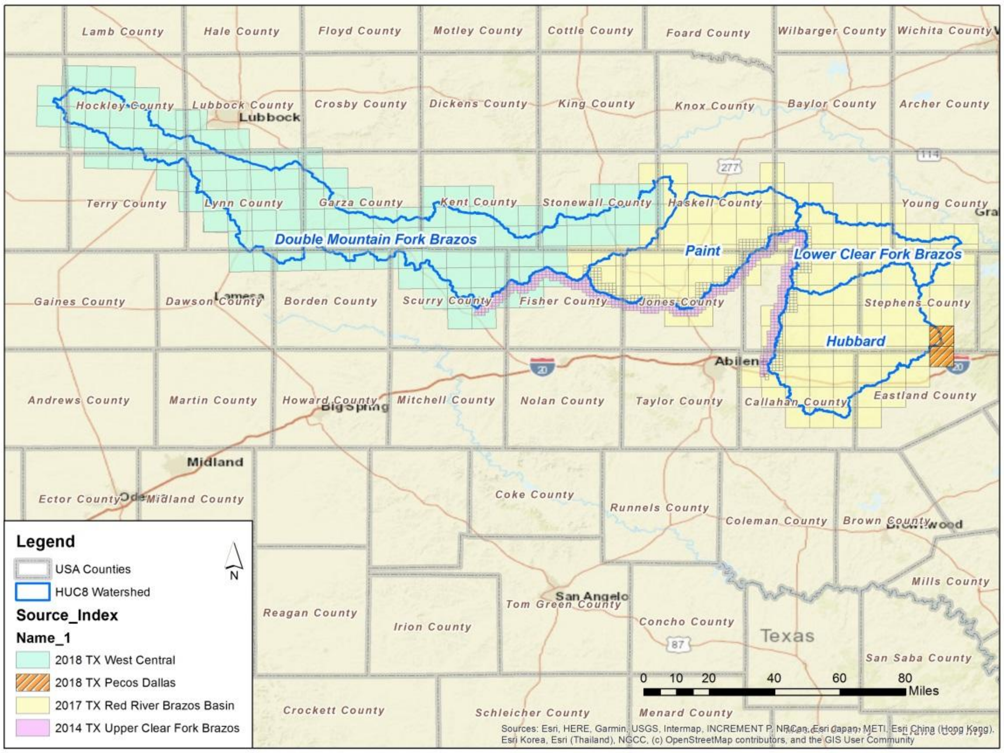

Figure 2: Task Order 1 BLE Source Terrain Data

2.1.2 Evaluation

A data coverage assessment was conducted to check for data gaps, extent, accuracy, and completeness. A review of related documentation, reports, indexes, and metadata associated with the leveraged datasets ensured each dataset meets FEMA accuracy requirements for topographic data. Decisions to leverage or exclude a dataset (or portion of it), were based generally on the following criteria coupled with engineering judgment:

- Data meet FEMA vertical accuracy standards (Table 1)
- Date of origination
- Data density and coverage

Table 1 depicts the Risk MAP SID #43 vertical accuracy requirements based on flood risk and terrain slope within the floodplain being mapped.

Table 1: FEMA Vertical Accuracy Requirements for Leveraged Data

Level of Flood Risk	Typical Slopes	Specification Level	Vertical Accuracy*	LiDAR Nominal Pulse Spacing (NPS)
High (Deciles 1,2,3)	Flattest	Highest	24.5 cm / 36.3 cm	≤ 2 meters
High (Deciles 1,2,3)	Rolling or Hilly	High	49.0 cm / 72.6 cm	≤ 2 meters
High (Deciles 2,3,4,5)	Hilly	Medium	98.0 cm / 145 cm	≤ 3.5 meters
Medium (Deciles 3,4,5,6,7)	Flattest	High	49.0 cm / 72.6 cm	≤ 2 meters
Medium (Deciles 3,4,5,6,7)	Rolling	Medium	98.0 cm / 145 cm	≤ 3.5 meters
Medium (Deciles 3,4,5,6,7)	Hilly	Low	147 cm / 218 cm	≤ 5 meters
Low (Deciles 7,8,9,10)	All	Low	147 cm / 218 cm	≤ 5 meters

*Vertical Accuracy at 95% Confidence Level (FVA or NVA)/(CVA or VVA)

Table 2 depicts the complete list of source elevation data and attributes leveraged for the Hubbard watershed. All datasets used for hydraulic analyses and mapping meet the highest specification level defined in Table 1. The following datasets were evaluated and prioritized as best available:

Table 2: LiDAR Topographic Data Available for the Hubbard Watershed

Year	Description	Source/Owner	Accuracy[1]	Approximate Footprint (mi^2)[2]
2018	2018 Texas Pecos Dallas LiDAR	USGS	12.2 cm	77
2017	2017 FEMA Region 6 TX – Brazos Basin LiDAR	FEMA	18.8 cm	2,126
2014	2014 Texas Upper Clear Fork Brazos LiDAR	FEMA	6.7cm	14

[1]RMSEz reported at the 95% confidence level

[2]Size of LiDAR DEM footprint utilized for BLE study

2.1.2.1 Hubbard Watershed Source Terrain Data

The source elevation data for the Hubbard watershed are DEMs derived from the 2018 Texas Pecos Dallas LiDAR; 2017 Texas Red River Brazos Basin; and the 2014 Texas Upper Clear Fork Brazos datasets. Only points classified as "ground" points (i.e., bare earth) were imported from the LiDAR and used for development of the project DEMs. Bare-earth LiDAR data are typically made by filtering non-ground returns (e.g. buildings, vegetation, etc.) from the raw laser returns. Figure 2 depicts the extent of the data defined in Table 2.

2018 Texas Pecos Dallas LiDAR

The 2018 Texas Pecos Dallas QL2 Lidar project covers the area along the boundary of the Hubbard HUC-8 watershed in Eastland and Stephens Counties, Texas (see Figure 3). The USGS contracted Digital Aerial Solutions, LLC to collect and process the data. The Lidar was collected March 16, 2019 to July 12, 2019. The source 1-meter bare earth DEM data was in UTM Zone 14N, NAD83, meters with elevations in NAVD88 (GEOID12B), meters.

The NVA of the Lidar point cloud was tested at 11.16 cm (19.6 cm required), and the NVA of the DEM was tested at 12.22 cm at the 95 percent confidence level. The Vegetated Vertical Accuracy (VVA) of the Lidar point cloud was tested at 16.99 cm, while the VVA of the DEM was tested at 16.06 cm at the 95 percent confidence level.

This data set was produced to meet American Society for Photogrammetry and Remote Sensing (ASPRS) "Positional Accuracy Standards for Digital Geospatial Data" (2014) for a 22.6 cm RMSEx / RMSEy Horizontal Accuracy Class which equates to Positional Horizontal Accuracy = +/- 78.3 cm at a 95 percent confidence level.

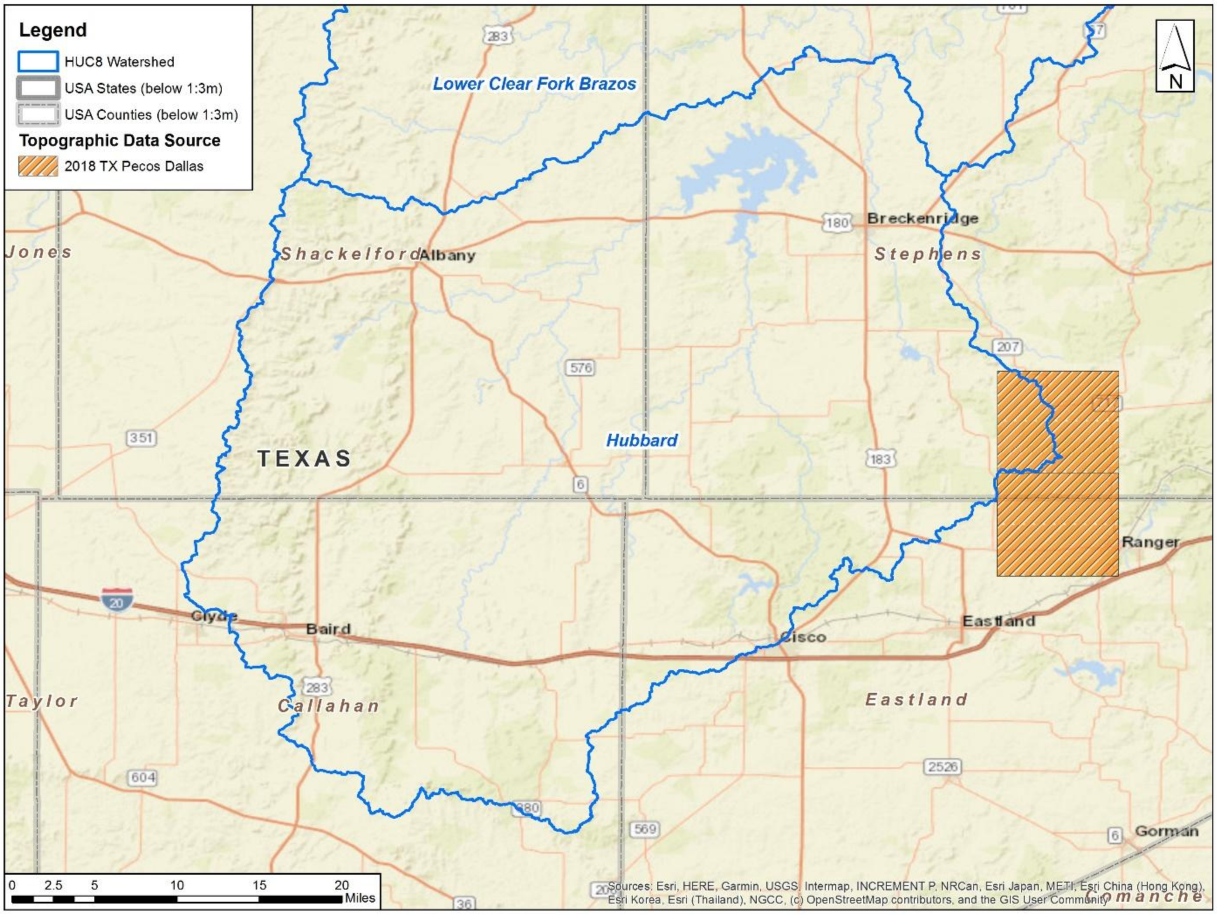

Figure 3: 2018 Texas Pecos Dallas LiDAR

2017 Texas Red River Brazos Basin LiDAR

The 2017 Texas Red River Brazos Basin Lidar project covers Callahan, Eastland, Fisher, Haskell, Jones, Shackelford, Stephens, Stonewall, Throckmorton, and Young Counties, Texas (see Figure 4). This data set covers the majority of the Paint, Lower Clear Fork Brazos, and Hubbard HUC-8 Watersheds. Dewberry served as the prime contractor for the project, and Leading Edge Geomatics Ltd. completed the Lidar data acquisition and data calibration for the project area. Lidar was collected between November 17, 2016 and May 28, 2018. The 1-meter bare earth DEM data was delivered in NAD83 (2011) UTM Zone 14N horizontal datum, NAVD88 vertical datum (GEOID12B), with horizontal and vertical units in meters.

The tested Root Mean Square Error (RMSEz) of the classified Lidar data vertical accuracy for checkpoints in non-vegetated terrain equaled 9.6 cm compared with the 10 cm specification. The NVA of the classified Lidar data computed using RMSEz x 1.9600 was equal to 18.8 cm, compared with the 19.6 cm specification. The tested VVA of the classified Lidar data computed using the 95th percentile was equal to 21.6 cm, compared with the 29.4 cm specification.

The horizontal accuracy, tested using NSSDA methodology at the 95 percent confidence level was computed as 88.4 cm (target was 100 cm).

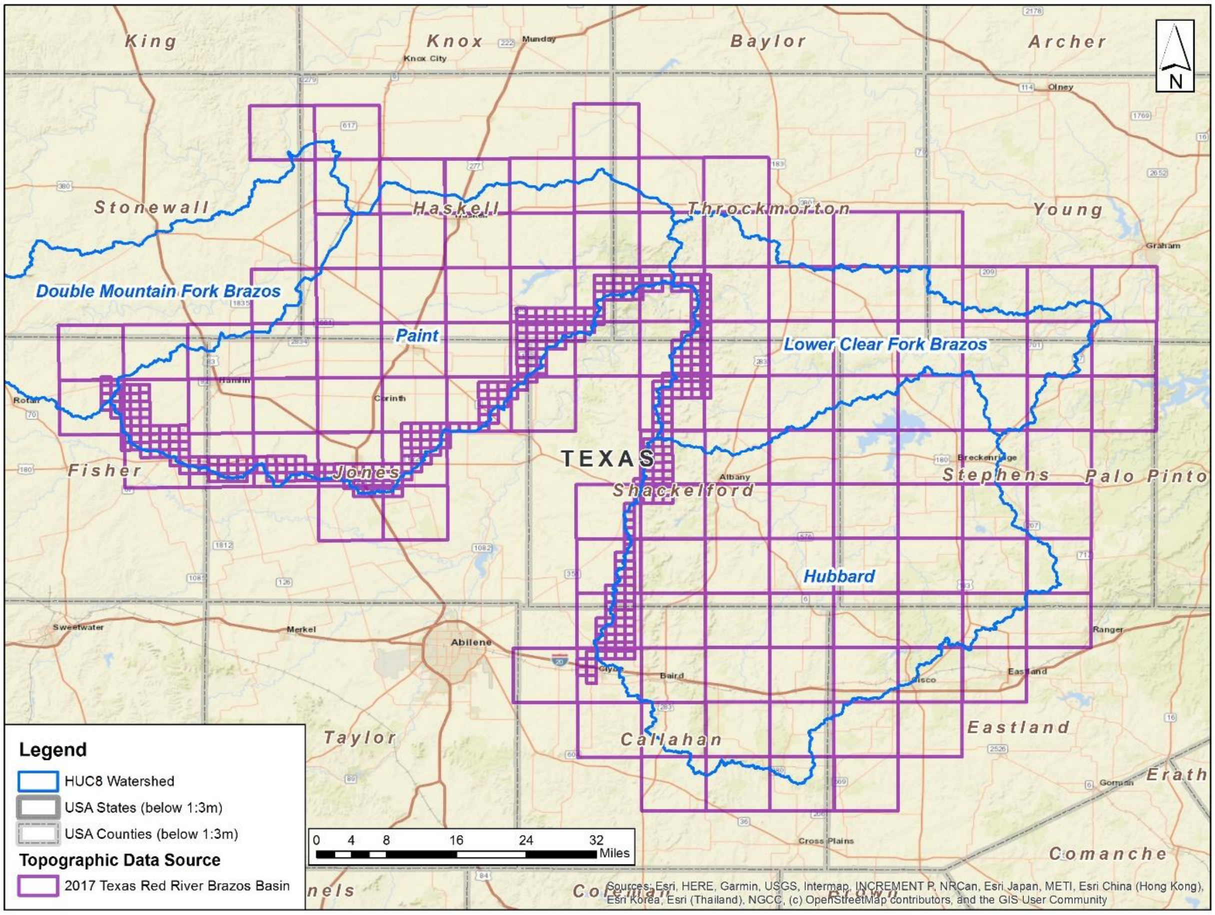

Figure 4: 2017 Texas Red River Brazos Basin LiDAR

2014 Texas Upper Clear Fork Brazos LiDAR

The 2014 Texas Upper Clear Fork Brazos QL2 Lidar project covers the buffer coverage along the southern border of the Double Mountain Fork Brazos and Paint HUC-8 Watersheds within Fisher, Jones, and Scurry Counties, TX. The data set also covers a small area in Callahan and Shackelford Counties, TX to provide adequate buffer coverage for the Hubbard HUC-8 Watershed (see Figure 5). Digital Aerial Solutions, LLC performed the Lidar data acquisition and data calibration for the project area. The data was collected December 12, 2014 through December 22, 2014. The 1-meter bare earth DEM data was delivered in NAD83 UTM Zone 14N horizontal datum, NAVD88 vertical datum, with horizontal and vertical units in meters.

The vertical accuracy tested RMSEz at the 95 percent confidence level was 3.10 cm compared to required accuracy of 9.25 cm. The NVA of the TIN tested RMSEz of 6.7 cm and 13.1 cm at the 95 percent confidence level in open terrain. The NVA of the DEM tested at an RMSEz of 6.7 cm and 13.0 cm at the 95 percent confidence level in open terrain. The tested horizontal accuracy was not provided within the Lidar project report.

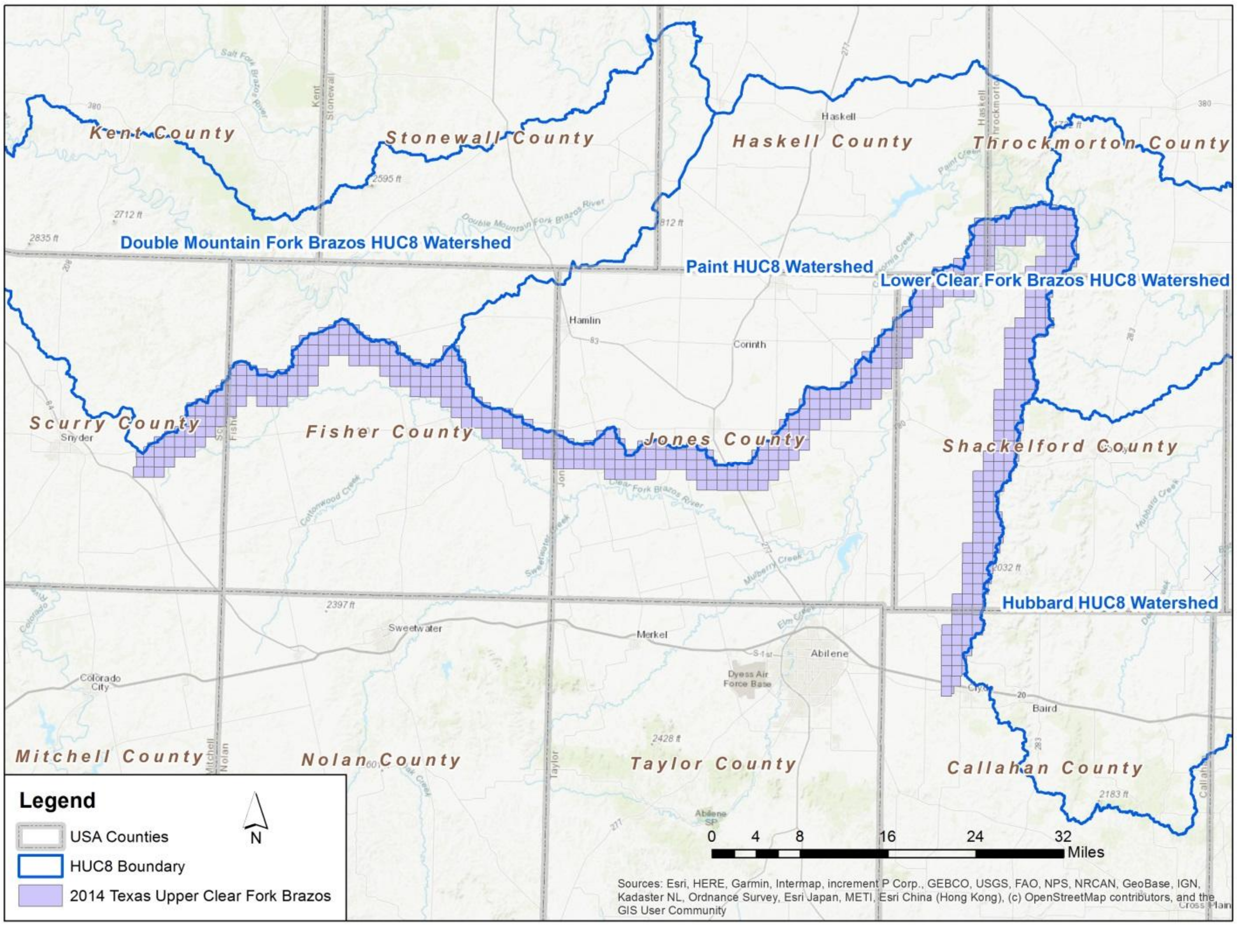

Figure 5: 2014 Texas Upper Clear Fork Brazos LiDAR

2.1.3 Data Processing

ArcGIS software was utilized in order to create a digital surface model for the Hubbard HUC-8 watershed project area. The LiDAR datasets were added to a mosaic dataset and prioritized by date with the most recent dataset taking the first priority. If two datasets are from the same year or flown at similar dates, the accuracy was reviewed to determine the priority. The mosaic dataset was exported to make a seamless bare earth DEM.

The exported DEM was reviewed through automated quality control (QC) to check for anomalies and outlier locations based on slope and cells that exceed z value differences from surrounding cells. Visual review was also performed to check for ground differences at the extents of the datasets for differences in ground values.

2.1.4 DEM QA/QC

DEMs developed for use in the Hubbard watershed BLE analysis were developed and independently assured to meet quality standards of the project. The data were developed using a controlled process, were evaluated and assured by a topographic data development team, and were evaluated and assured by the engineering team. Quality assurance (QA) during the data development process includes, but is not limited to the following QC checks:

- Horizontal Projection Check
- Vertical Datum Check
- Resolution Check
- Format Check

- Seamless Data Check to ensure the DEM files are consistent and seamless along source data edges

The QC after the development process by the DEM development team included visual observations using hillshade, contouring, color rendering, and/or other visual aids to review and identify potential impactful anomalies within the DEM surface. This QC step included, but was not limited to the following QC checks:

- Seamless Data Check to ensure no voids along the edges and between the prioritized datasets
- NoData Value Check to ensure no null values
- Manual Elevation Check using hillshade rasters to find erroneous elevation issues
- Unit Consistency Check
- Legacy Cell Value Anomalies

QA conducted after the seamless DEM development conducted by the engineering team included visual or automated assessments to identify potentially impactful anomalies or slope changes that may adversely impact hydraulic analysis.

The final DEM data developed for the Hubbard watershed is assured to meet FEMA standards and present a representative surface developed from leveraged elevation data for the purposes of this BLE project.

2.2 2D BLE Methods

RAS6 2D hydraulic modeling and rain-on-grid utility was applied in the Texas 2D BLE products workflow. The following sections describe the engineering methods and model inputs used.

2.2.1 2D Computational Mesh and Settings

Due to the size of the Hubbard watershed (approximately 1,300 sqmi), the HUC-8 was split into two separate HEC-RAS geometries, due to computational and modeling limitations, as shown in Figure 6. The HUC-8 was split into Hubbard Creek and Gunsolus Creek modeling areas. Initially model area footprints were aligned with HUC-10 boundaries, combining some where the size of the smaller HUC-10s allowed. Minor adjustments were made to those initial model area footprints to improve modeling and/or mapping efficiency. The RAS6 boundaries were created for the model areas using ArcGIS toolsets, which reduce the need for manual edits to mesh cells within RAS6 that can result in error generation. The perimeter of Gunsolus Creek model, which connects downstream with the Lower Clear Fork Brazos HUC-8, was extended beyond the HUC-8 boundary to assist with mapping tie-in with the downstream model. The Hubbard Creek and Gunsolus Creek 2D meshes contain more than 674,000 cells and 645,000 cells, respectively, consisting of 200 foot cells, with the exception of 100 foot cells along the 1 square mile streams and 50 foot cells within community boundaries, using refinement regions. Within community boundaries the streamlines were also extended to the 0.5 square mile extent and assigned 50 foot cell spacing in order to be more detailed. Internal connections were used to extract flow readings for gage locations throughout the model, while profile lines were used for all other flow extractions. An adaptive 1 minute time step was used to allow the model to lower the time step, as necessary, to keep the maximum courant number under 3 for the duration of the simulation. The time step was allowed to reach 64.00 minutes for a maximum and 7.50 seconds for the minimum. A theta value of1.0 was used. The RAS6 model was run with Diffusion Wave (simplified Full Momentum) equations.

2.2.2 Model and Boundary Condition Setup

Using RAS6 rain-on-grid modeling requires a 2D computational mesh boundary and often requires defining inflow boundary conditions and application precipitation values. Spatially varying precipitation DSS values were applied as a meteoreological Data Boundary Condition. The process to determine the spatially varied precipitation DSS values to be applied is outlined in the hydrology section. Figure 6 depicts the Hubbard Creek and Gunsolus Creek model boundaries, flow transition points between models, and all USGS stream gages in the watershed. Although there are many gages present in the watersheds, only four were used in the study.

Outflow boundary conditions (from the computational 2D mesh) were used along model boundaries without an inflow boundary condition. Because the Hubbard HUC-8 was split into two work areas, the outflow from the Hubbard Creek model along Hubbard Creek was used as an inflow hydrograph for the Gunsolus Creek model area. This hydrograph was extracted from the Hubbard Creek model using a 2D connection, and then placed as a flow hydrograph external boundary condition for the Gunsolus Creek model.

Unique outflow boundaries were established for obvious riverine outflows, while the remaining boundaries were defined as continuous boundaries to allow drainage to adjacent basins to leave the model area freely. Normal depth was used for all non-unique outflow boundary conditions using approximate energy grade-line slopes estimated from the LiDAR terrain data.

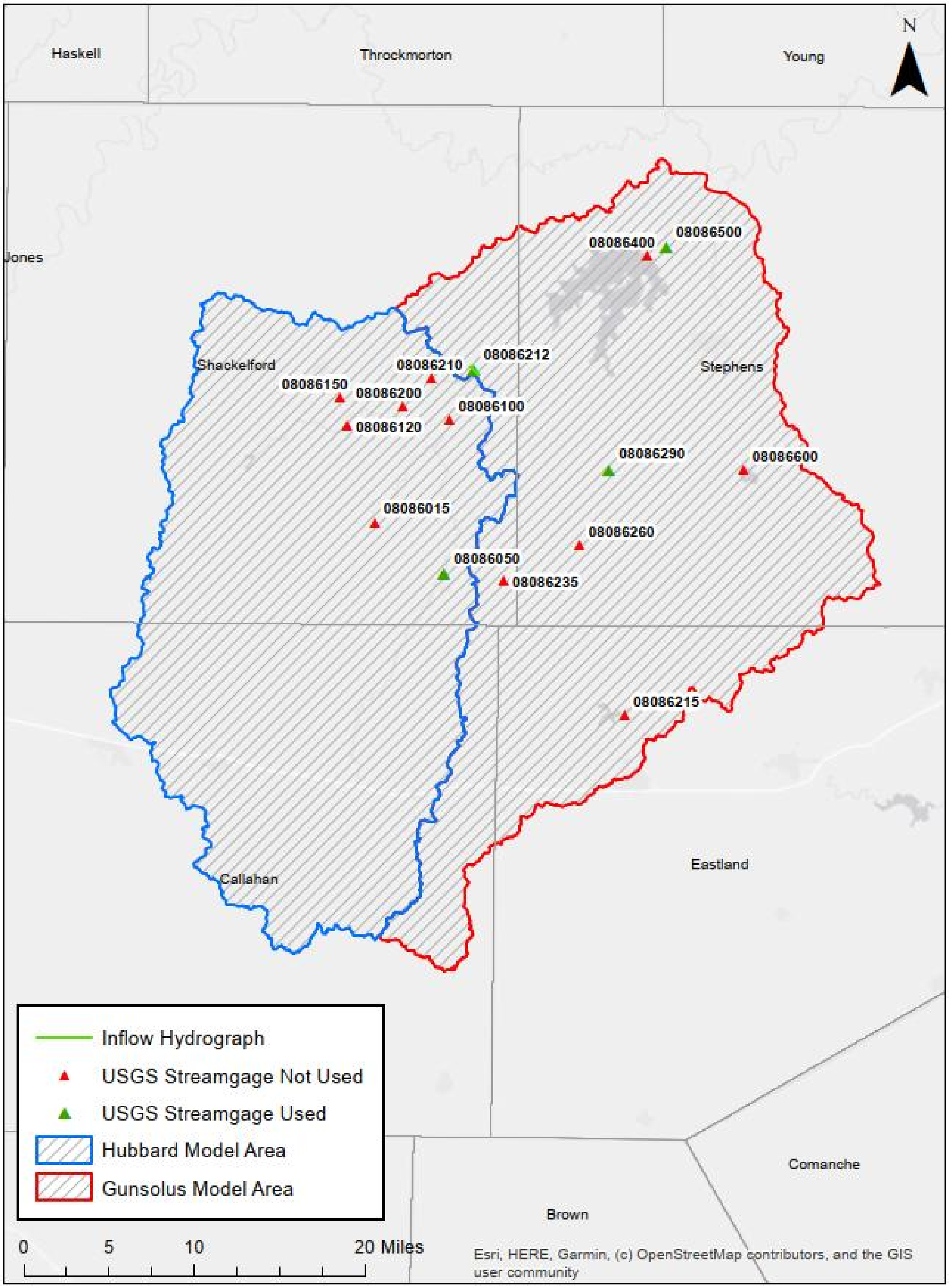

Figure 6: RAS5 2D Computational Mesh and Boundary Conditions and USGS Peak Streamflow Gages

2.2.3 Hydrology

RAS6 (specifically version 6.1, used for this anslysis) can implement spatial precipitation and infiltration methods. This capability has improved the efficiency and hydrologic representation of a study area. RAS6 cannot directly import ASCII format gridded precipitation data. Therefore, spatially varied precipitation Data Storage System (DSS) files were used for the precipitation hyetograph boundary condition in the RAS6 hydraulic models.

2.2.3.1 Precipitation Frequencies

Precipitation frequency data from NOAA's Atlas 14 Precipitation Frequency Data Server (PFDS) was used for this study (NOAA, 2018). The 10-, 4-, 2-, 1-, and 0.2-percent-annual-chance precipitation depths for the 24-hr duration were determined by area-weighted intersection of the gridded PFDS data with the model area boundaries. Specifically, precipitation depths for return periods as rare as 1-in-1,000 annual chance for the state of Texas are available as raster data with 1/12-degree spatial resolution. No areal reduction factors were applied to these depths for any of the model areas since it would be inappropriate for the majority of smaller-sized tributaries within each model; however, flow and stage results throughout the model area were analyzed against historic gage and previous study data as discussed later in the Calibration and Validation section of the report.

The 1-percent-plus flood elevation is defined as the flood elevation using discharges at the upper 84% confidence limit for the 1-percent-annual-chance flood. Similarly, the 1-percent-plus flood elevation is derived using discharges at the lower 84% confidence limit for the 1-percent-annual-chance-flood. The plus and minus standard error was determined as the upper and lower 84% confidence limits (i.e., the 68-percent confidence interval) on the nominal 1-percent depth. In addition to recurrence interval precipitation estimates, 90% confidence intervals of reported Atlas 14 precipitation values are provided on the PFDS (NOAA, 2018). On a normal distribution curve, 90% confidence intervals (i.e., the upper and lower 95% confidence limits) correspond to +/- 1.645 standard deviations. The 1% plus and minus events are defined to be one standard deviation above and below the 1% event, so the provided 95% confidence limits were used to determine the 84% confidence limits using this relationship.

The 1%-plus and 1%-minus storm events were defined by utilizing a 68% confidence interval around the 1% event. The 68% confidence interval was estimated using the following equations:

$$\widehat{\sigma} = \frac{X_{95} - X_{05}}{Z_{95} - Z_{05}}$$

$$CI_{68} = (X - \widehat{\sigma}, X + \widehat{\sigma})$$

Where :

1. $\widehat{\sigma}$ represents the standard deviation of an assumed normal distribution around the NOAA Atlas 14 frequency estimates.
2. X95 and X05 represent the upper and lower estimates of the 90% confidence interval, respectively.
3. Z95 and Z05 represent the corresponding z-scores of the upper and lower estimates, respectively (i.e., Z95 = 1.645; Z05 = -1.645).
4. CI68 the 68% confidence interval is approximated by applying one standard deviation above and below the baseline 1% storm event.

2.2.3.2 Temporal Rainfall Distribution

Temporal rainfall distributions were computed for the Hubbard HUC-8 model areas following the NRCS synthetic rainfall distribution procedure as described in the National Engineering Handbook Part 630 – Chapter 4 (NRCS, 2019). NOAA Atlas 14 data was extracted for the areas, and a unique 24-hour temporal distribution was computed for each recurrence interval. The temporal distributions are expressed in probability terms as cumulative percentages of precipitation totals at various time steps. The NOAA Atlas 14 precipitation-frequency grids only provide total depths for each frequency. Precipitation grids were spatially distributed across the 24-hour duration using a 6-minutes time series data shown in Figure 7. The resulting 6-minute interval precipitation grids were used to develop spatially distributed precipitation DSS data for the model areas. The “Meteorological Data” tab under the Unsteady Flow Boundary Conditions editor in RAS6 was used to import the spatial precipitation DSS data into the 2D hydraulic model.

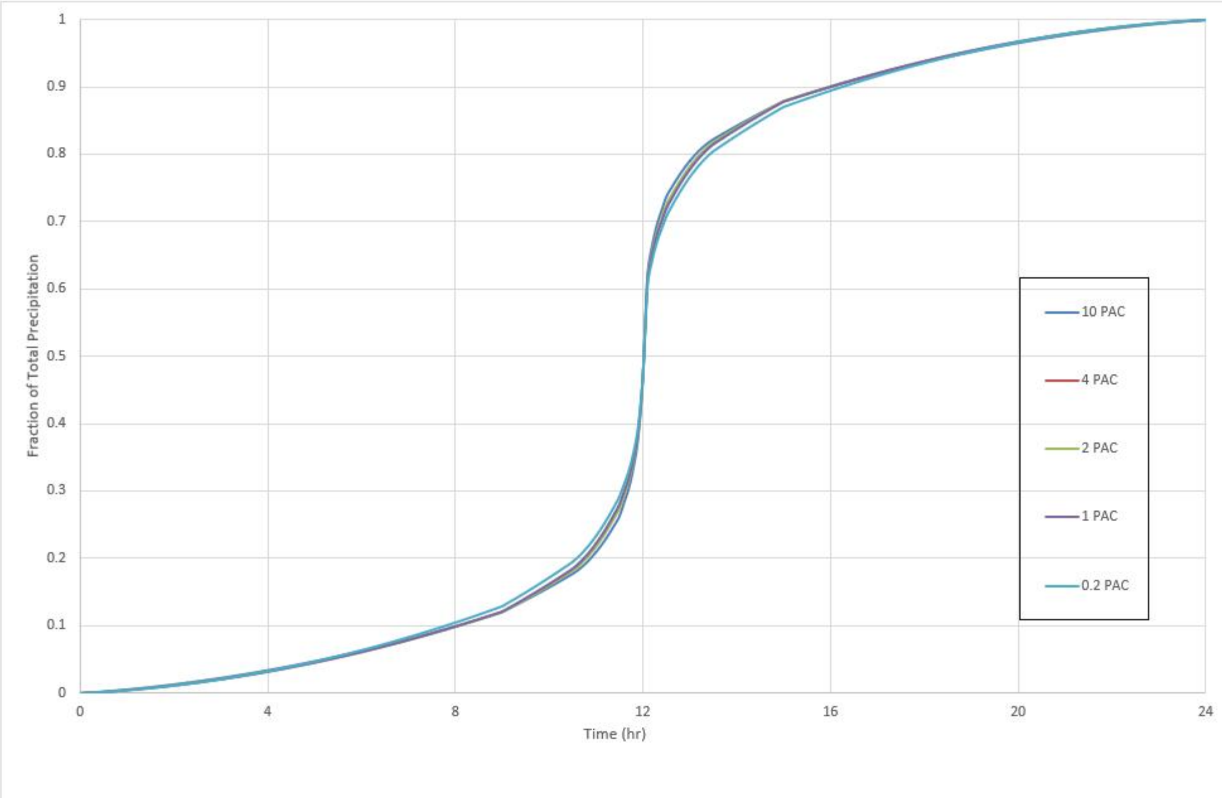

Figure 7: NRCS Nested Rainfall Distributions for the Hubbard HUC-8 Watershed BLE Study

2.2.3.3 Infiltration Parameters

The infiltration layer containing attributes for Soil Conservation Survey (SCS; now the Natural Resources Conservation Survey (NRCS)) curve numbers (CN), abstraction ratio, and minimum infiltration rate was initially calculated in ArcGIS using the National Land Cover Database (NLCD, 2019) and NRCS soil data. This infiltration layer was then imported to the RAS6 2D hydraulic model where it is then used to estimate rainfall-runoff losses and surface runoff used in the hydraulic calculations.

A land use-soils-CN matrix can be used to determine CN for a particular study area. Table 3 details soil-water balance model lookup table for determining CN’s for the intersection of soils and land use. The CN values are sourced from the NRCS’s TR-55 (USDA, 1986). This matrix is intended as a general guide and then adjusted based on engineering judgment, as well as during calibrations and validation of the model, for a given study area.

Table 3: Land Use(LU)-Soils-CN Matrix for Defining Initial Curve Number

LU_GridCode	NLCD LU Description	Hydrologic Soil Group			
		A	B	C	D
11	Open Water	100	100	100	100
12	Perennial ice/snow	40	40	40	40
21	Developed Open Space	49	69	79	84
22	Developed Low Intensity	77	86	91	94
23	Developed Medium Intensity	89	92	94	95
24	Developed High Intensity	98	98	98	98
31	Barren Land	77	86	91	94
41	Deciduous Forest	32	48	57	63
42	Evergreen Forest	39	58	73	80
43	Mixed Forest	46	60	68	74
52	Shrub Scrub	49	68	79	84
71	Herbaceous	64	71	81	89
81	Hay Pasture	49	69	79	84
82	Cultivated Crops	71	80	87	90
90	Woody Wetlands	88	89	90	91
95	Emergent Herbaceous Wetlands	89	90	91	92

2.2.3.4 USGS Gage Analysis

The models were compared to known USGS peak flows to validate model results. USGS stream gages with less than 10-years of record were not considered for hydrologic analysis or for calibration. In addition, gage 08079000 was not utilized because of the gage data was approximately 41-years old and since then the land cover and development (structural, dams, canals, diversions, etc) have changed in the region, which is evident by comparing 2001 NLCD and 2016 NLCD land cover. Due to these reasons,this gage is no longer a true representation of present conditions. USGS gages 08086050, 08086212, 08086290, and 08086500, the gages used for analysis in this study, are listed in Table 4, below.

Table 4: USGS Peak Streamflow Gages

Model Area	Gage ID	Flooding Source and Location	Published Drainage Area (mi^2)	Period of Record
Hubbard Creek	08086050	Deep Ck at Moran, TX	235	35
	08086212	Hubbard Ck bl Albany, TX	613	56
Gunsolus Creek	08086290	Big Sandy Ck abv Breckenridge, TX	280	61
	08086500	Hubbard Ck nr Beckenridge, TX	1,092	39

2.2.3.5 Inflow Hydrograph Boundary Conditions

Downstream outflow from Hubbard Creek in the Hubbard Creek Model was used as an inflow into the Gunsolus Creek model. The inflow hydrograph was derived by utilizing the results of the RAS6 model for Hubbard Creekdirectly upstream. By using upstream model results as inflow hydrographs to the downstream model, this allows the two separate hydraulic models to act as one continuous model of the larger Hubbard HUC-8 watershed area. The inflow hydrograph was extracted from the Hubbard Creek model using a 2D connection. The inflow hydrograph applied to Gunsolus Creek RAS model is represented in Figure 8.

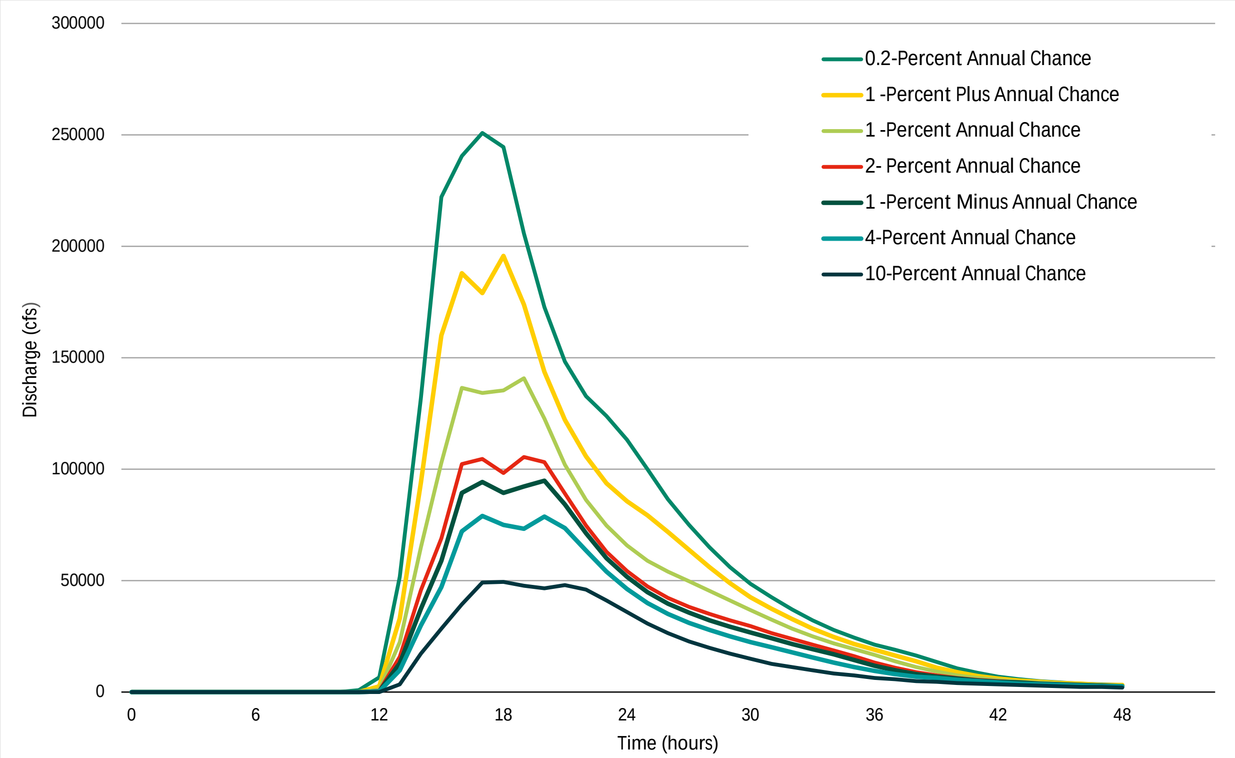

Figure 8: Inflow Hydrograph from Hubbard Creek

In order to achieve a seamless flood hazard result at a transition location (locations where flow is exchanged between 2D model areas), the water surface elevation (WSE) and inundation tie-ins between models must be made as close as possible. A 1,000 feet buffer was applied to each model work area for the mesh boundary. This is done so that the inflow boundary condition of the downstream model and the normal depth outlet boundary condition of the upstream model are far enough away from the work area transition location that they do not impact the WSE tie-ins between models in an undesired way. To make this overlap work without double accounting for rainfall, an internal 2D connection is placed in the upstream model at the exact same location as the inflow boundary condition for the downstream model. Approximately halfway between the model overlap is the actual model area boundaries where the mapped floodplain products switch from the upstream model results to the downstream model results. This transition location is the targeted area to have the water surface elevation and inundation tie-in as closely as possible.

2.2.4 Hydraulics

This section describes the remaining hydraulic modeling considerations, including implementation of Manning's roughness, breaklines, refinement regions, and hydraulic structures within the 2D computational mesh.

2.2.4.1 Roughness Coefficients

Manning's n roughness coverage was developed for the 2D computational mesh using typical roughness values for given NLCD land classifications. Manning's n values were used for all areas outside of the channels of the stream network, with one Manning's n value assigned to the stream channels. The channel layer was created using a 100 foot buffer. This allows for the model to accurately represent deep, swift flow within the channel and shallow overland flow outside of the channel areas. The table below shows a typical landuse-roughness matrix used in defining the roughness coverage for the study area for areas both inside and outside of the channel. Sources cited in the table were used to associate typical n values with the NLCD classifications.

Table 5: NLCD 2016 Manning's n Roughness Matrix

NLCD Classification	N Value	Source
Stream Channel	0.04	NRCS KS Dam Breach, 2016, Chow, 1959
Open Water	0.04	NRCS KS Dam Breach, 2016, Chow, 1959
Developed, Open Space	0.04	NRCS KS Dam Breach, 2016, Chow, 1959
Developed, Low Intensity	0.08	NRCS KS Dam Breach, 2016, Chow, 1959
Developed, Medium Intensity	0.1	NRCS KS Dam Breach, 2016, Chow, 1959
Developed, High Intensity	0.15	NRCS KS Dam Breach, 2016, Chow, 1959
Barren Land	0.025	NRCS KS Dam Breach, 2016, Chow, 1959
Deciduous Forest	0.16	NRCS KS Dam Breach, 2016 , Chow, 1959
Evergreen Forest	0.16	NRCS KS Dam Breach, 2016, Chow, 1959
Mixed Forest	0.16	NRCS KS Dam Breach, 2016, Chow, 1959
Scrub/Shrub	0.1	NRCS KS Dam Breach, 2016, Chow, 1959
Grassland/Herbaceous	0.035	NRCS KS Dam Breach, 2016 , Chow, 1959
Pasture/Hay	0.03	NRCS KS Dam Breach, 2016, Chow, 1959
Cultivated Crops	0.035	NRCS KS Dam Breach, 2016 , Chow, 1959
Woody Wetlands	0.12	NRCS KS Dam Breach, 2016, Chow, 1959
Emergent Herbaceous Wetland	0.07	NRCS KS Dam Breach, 2016, Chow, 1959

2.2.4.2 Breaklines

Breaklines align grid cell faces and were used within the 2D mesh area to define prominent features including road embankments and hydraulic structures. Road embankment features were delineated in GIS and imported into the RAS6 model as breaklines to contain water where appropriate. Similarly, significant bridge/culvert crossings that were not processed out of the terrain data were modeled by v-notch breaklines adjacent to the road embankment to align grid cells around the embankment and allow water to be routed through the embankment without creating artificial backwater. An example of the v-notch breakline approach is shown in Figure 9.

County, interstate, common name, state recognized, and U.S. roads were incorporated for road breaklines from the U.S. Census Bureau TIGER/Line road layer.

The SA/2D connections placed on the Hubbard Lake Dam, Cisco Lake Dam, and Lake Daniel Dam were enforced as breaklines. Private dams were not modeled as showing protection. This is to lessen the burden on private dam owners to maintain their dams in order to sustain the regulatory products that could be created in the future as a result of this study. The study area does not include any FEMA accredited levees.

Breaklines were also used along all the stream centerlines of streams draining greater than one square mile of drainage area, and 0.5 square miles of drainage area within densely populated areas. Each streamline was topo-derived and the stream centerline was enforced with 100 foot cell spacing in order to align cells along the stream line and capture more detail along the one square mile stream network. Streamline alignment was also hand checked with the terrain by the modeler to ensure accuracy. Stream names were referenced from other sources such as NFHL and NHD datasets. In the Hubbard Creek model area, some streamlines were enforced to 75 foot cell spacing rather than 100 foot in order to address cell face errors around sharp curves in the streams. In the RAS6 model, streams that passed through densely populated regions were enforced as breaklines using 50 foot cell spacing.

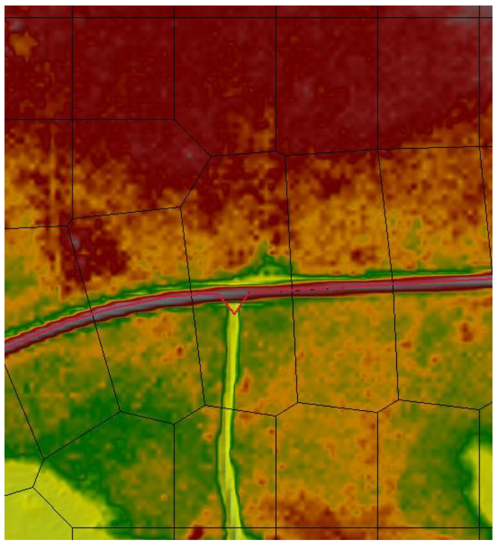

Figure 9: V-notch Breakline Approach at Bridge Crossing

2.2.4.3 Refinement Regions

Refinement regions were created for each community within the model. The political boundary was used to determine the shape of the refinement region. The regions were assigned a cell spacing of 50 foot by 50 foot. This finer cell spacing allows for more hydraulic calculations and mapping detail near areas where there are likely to be more structures. Table 6 shows the communities contained within Hubbard HUC-8 watershed that were modeled with refinement regions as well as the square mileage of the community.

Table 6: Communities with 2D Mesh Refinement

Community Name	Area (mi^2)
Albany	1.96
Baird	2.77
Breckenridge	4.74
Cisco	4.86
Moran	0.46
Putman	1.02

2.2.5 Quality Control

The 2D BLE results were independently assured to meet quality standards of the project. Standard checklists complying with FEMA standards were used to review hydrology and hydraulics results, the resulting flood hazard area delineations and CNMS dataset. Quality assurance during the data development process includes, but is not limited to the following QC checks:

- Hydrological QC – included checks for curve number calculation, input precipitation, flood events, areal reduction factor and human error.
- Hydraulic QC – included checks for RAS geometry, breakline placement, v-notch placement to ensure water conveyance at crossings, refinement regions, roughness coefficients, boundary/initial conditions, timestep and mapping outputs
- Mapping – included checks for spot checking flood inundation accuracies based on floodplain mapping criteria described in section 4.1.2 ensuring flood extents from higher frequency events did not exceed lower frequency extents due to GIS smoothing algorithms, and topological overlap and cluster tolerance errors were resolved
- CNMS - Included review of the A1-A5 analysis for all effective approximate reaches in the HUC, geometry updates to newly studied reaches added as Zone X, and removal of scoped areas which lie outside of the final BLE footprint.

3. Results

The 2D BLE results for the study produced flood hazard area that compared reasonably well with effective SFHA in most cases, and provides additional estimated flood hazard risk area where not previously mapped. The RAS6 peak (max) results were exported for mapping and the RAS6 model was run with a hydrograph output interval of 30 minutes, mapping output interval of 1 hour and the detailed output interval of 1 hour. The Hubbard HUC-8 2D BLE watershed is sufficient to facilitate FEMA regulatory processes while also providing the best available information for planning purposes.

To further check the models accuracy additional profile lines were added and compared to Base Flood WSE that were available in the Shackleford County Flood Insurance Study (FIS) dated July 18, 1986, and the Stephens County FIS, dated April 5, 2019. The comparison is shown below in Table 7. The 2D BLE results should be verified through community work map meetings as part of the regulatory workflow.

Table 7: Effective and Model Base Flood Elevation(BFE) Comparison After Calibration

Model Area	Location Description	Effective BFE (feet)	Model BFE (feet)	Difference (feet)
Hubbard	Cross Section A (Approx) on North Salt Prong Creek	1,388.5	1,388.7	0.2
Hubbard	Cross Section B (Approx) on North Salt Prong Creek	1,398.1	1,397.1	-1.0
Hubbard	Cross Section E (Approx) on North Salt Prong Creek	1422.2	1421.6	-0.6
Gunsolus	East Walker Street	1185.0	1184.0	-1.0
Gunsolus	Highway 287	1175.0	1174.5	-0.5
Gunsolus	Lindsey St/Court Ave	1183.0	1183.8	0.8
Gunsolus	Live Oak Ave	1195.0	1194.2	-0.8
Gunsolus	Shelton Ave	1200.0	1199.0	-1.0
Gunsolus	Miller Ave	1192.5	1192.8	0.3

3.1 Calibration

Known USGS gages within the model area with more than 10-years of flow record were used as the first priority for calibration of the 1-percent annual chance event. Discharges at gages were compared to discharges in the 2D models at the exact same locations. If a published rating curve was available, WSEs from the model was compared to the calculated 1-percent WSEs from the gage analysis. For both Hubbard and Gunsolus modeling areas, known WSEs were used for validation, not calibration. Hubbard Creek was calibrated using USGS gages and supplemented with regression equations. Gunsolus was calibrated using USGS gages and supplemented with FIS data points.

Four USGS gages that fall within the boundary of the Hubbard HUC-8 watershed were utilized for calibration purposes, two in Hubbard study area and two in Gunsolus study area. Regression equations were used for secondary calibration in the Hubbard Creek model area, but priority was given to the USGS gage analysis results. The regression analysis was performed as per regional regression equations using the drainage area, dimensionless main channel slope (S), OmegaEM parameter and mean annual precipitation (P) (USGS- SIR 2009-5087). Regression comparisons were made in 2 locations with varying contributing drainage area to ensure a reasonable amount of excess precipitation was being applied to the 2D mesh.

Adjustments to hydraulic features within the model were made until the flows in the model matched closely with the peak flows estimated from gage and effective data. An adjustment of -22 to the curve numbers made for the model calibration for Gunsolus. For the Hubbard Creek model, an adjustement of -25 to the curve numbers was made for the drainage area draining to the upstream USGS 08086050; for the remainder of the watershed, no adjustement was made in curve number or the n-values. Final results following model calibration at the calibration locations were presented in Table 8.

Table 8: Calibration Results

Study Area	Calibration Location	Source	Method Used	Reference			HEC-RAS 6.1.0 (2D) (cfs)
				Lower Limit (cfs)	1-percent (cfs)	Upper Limit (cfs)	
Hubbard Creek	Gage 08086050	USGS	PeakFQ	15,030	18,620	25,070	24,625
Hubbard Creek	Gage 08086212	USGS	PeakFQ	90,370	131,000	215,600	140,946
Hubbard Creek	Deep Creek Upstream of Confluence with Mexia Creek (Basin 1)	USGS-SIR 2009-5087	Regression Equations	4,497	8,972	17,901	12,894
Hubbard Creek	Hubbard Creek Upstream of Road FM 576 (Basin 2)	USGS-SIR 2009-5087	Regression Equations	5,880	11,732	23,408	29,358
Gunsolus Creek	Gage 08086290	USGS	PeakFQ	17,266	34,450	68,737	29,604
Gunsolus Creek	Gage 08086500	USGS	PeakFQ	22,097	44,090	87,971	16,383

Figure 10 and 11 show the final results of the calibration locations compared to modeled flows throughout the Hubbard Creek model areas along with error bars created using the difference between 1-percent and 1-percent plus discharges and 1-percent and 1-percent minus discharge as minimum and maximum values. For Gonsulos Creek, seven comparisons were made with varying drainage areas to ensure the calibration of excess precipitation for different points over the entire watershed area. For Hubbard Creek, four points were compared with two of those being USGS gages. This large collection of calibration points provides confidence in results throughout the entire watershed.

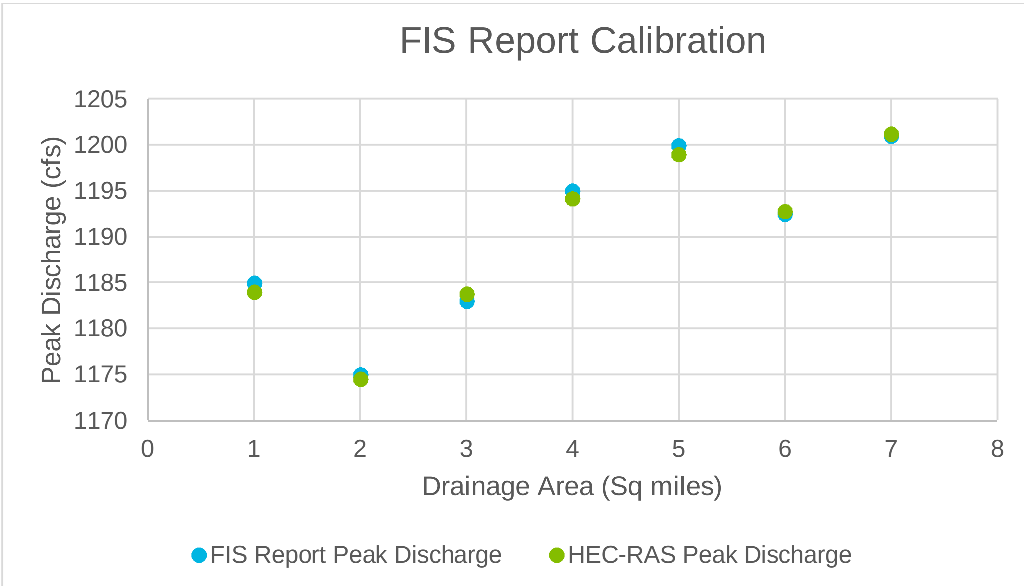

Figure 10: Calibration Comparison for Gunsolus Creek

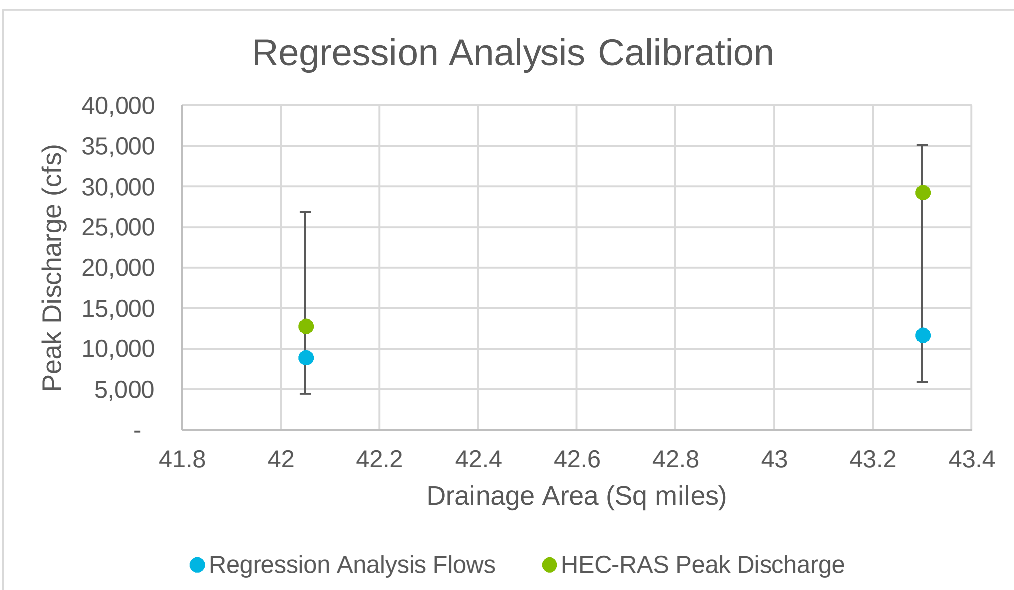

Figure 11: Calibration Comparison for Hubbard Creek

3.2 Challenges

There was no developed rating curve available for the Hubbard Lake Dam. An outflow rating curve was developed using aerial imagery and properties of the of the dam and morning glory spillway gathered from the Volumetric Survey of Hubbard Creek Reservoir Report (TWDB, June 2018), available from the TWDB website.

During quality control review, it was commented that while analyzing the Gunsolus model inundation over time, it appeared as if the model cells along the dam may be leaking. Several methodologies were attempted to determine if this was, in fact, due to leaking. Testing included modifying cell boundaries, checking the enforcement of the SA/2D connection as a breakline, and updating/revising the dam's terrain modification. None of the sensitivity analysis changes changed the inundation in that location, and it was concluded that the inundation adjacent to the dam is due to precipitation rather than the leaking of the dam.

In order to allow for a better tie-in to the downstream Lower Clear Fork Brazos HUC-8 model, the downstream portion of the Gunsolus model was slightly extended beyond the HUC-8 boundary. The WSE of Lower Clear Fork Brazos model at the downstream most point of the Gunsolus model was utilized as the downstream boundary condition.

For the Hubbard Creek model area, Basin 2 was not a reliable data point to calibrate using regression equations as it is on the main stem of Hubbard Creek. Because there are many dams in the watershed, there were no other subbasins that could be used to calibrated using regression equations. Hubbard Creek had reliable gage data and calibrated to those points and the Basin 1 regression equation location, and therefore no other methods needed to be explored.

No other challenges were identified in the Hubbard Creek model area.

3.3 Recommendations

This study provides significant information useful for flood identification and communication among those affected. The study is highly scalable, and stakeholder input and further analysis would enhance the product and inform implementation of regulatory flood hazard areas. In addition, the validity of the 2D BLE results should be verified through community work map meetings before being applied as a regulatory product.

Due to the size of the RAS6 hydraulic model, nominal 200 foot cell sizes are utilized with refinement areas (and smaller cell sizes) implemented in specific areas of interest, as described in the modeling sections above. For detailed modeling and further improvements, smaller sized model is recommended to allow further refinement of infiltration parameters as well as use of a smaller cell sizes, along with addition of structural and survey data for each crossing.

4. Floodplain Mapping and Effective Zone A Validation

The following sections provide a synopsis of how raw modeled depths were translated into Special Flood Hazard Areas (SFHA). In addition to developing a new SFHA, the BLE model data was leveraged to validate the effective Zone A studies within the project footprint.

4.1 Special Flood Hazard Area

4.1.1 Model Outputs

The HEC acknowledged RAS Mapper may not render water surface elevation values and/or delineate inundation extent appropriately for direct use in FEMA regulatory mapping products. To maintain a high level of consistency between modeling results and final mapping, minimal map clean up was performed while maintaining identification of both fluvial and pluvial flood risk as reflected by the models. Additional processing may be required to make the mapping products FEMA compliant.

4.1.2 Methodology

The sloping render mode plots water surface elevation (WSE) by interpolating the WSE between the 2D cell faces, producing a more continuous flood inundation extent. Depth rasters from the sloping render mode were exported for the 10-percent, 1-percent, and 0.2-percent flood events with a tolerance of 0.001 feet. To reduce the extent of disconnected flood areas, raster grid processing is used to filter and remove disconnected, small, or shallow areas of flooding by processing through the 'Mapping Threshold Matrix' shown in Table 9.

Table 9: Mapping Threshold Matrix

Area (acres)	Average Depth (feet)
< 0.33	-
0.33 – 0.5	< 0.5
0.5 – 1.0	< 0.33
1.0 – 2.0	<0.1

Polygon outputs from the 'Mapping Threshold Matrix' also fill in minor areas of high ground (islands) that are less than 0.33 acre. The outputs are then modified through a Simplication and Smoothing process to reduce unnecessary/erroneous vertices, remove rough edges and reduce the size and complexity of the raw floodplain polygons for the 1-percent, and 0.2-percent flood events. For the Hubbard watershed, the polygon outputs were simplified by retaining critical points at a 5 foot tolerance. The simplified polygon outputs were then smoothed utilizing the PAEK algorithm and the tolerance was set to 25 feet. The 10-percent flood event polygons are not modified through the simplification and smoothing process and are delivered in the rasterized polygon shape.

Due to topographic differences within a lake footprint, these areas sometimes appear partially mapped in the flood extents from the model results. Lakes and reservoirs larger than 40 acres are reviewed to ensure full inundation on the 1-percent, and 0.2-percent polygon extents. If necessary, lake boundaries were copied into the flood event polygons to make sure they are fully mapped.

Once the final polygon flood extents are complete, it is necessary to merge the 10-percent boundaries into the 1-percent and the 1-percent extents into the 0.2-percent extents. This step ensures that the extents of the 10-percent floodplain is smaller than the 1-percent floodplain, and the 1-percent is smaller than the extents of the 0.2-percent floodplain.

4.1.3 BLE Flood Hazard Layer

BLE database format FLD_HAZ_AR feature classes were developed and attributed with Zone A and Shaded Zone X features. The BLE FLD_HAZ_AR feature class was tested for topological errors described in the FIRM Database Technical Reference and all errors were fixed for data integrity and BLE-schema agreement. The 10-percent boundaries have been included in the BLE TENPCT_FP feature class.

4.1.4 Additional 1-Percent Features

The BLE results for this study produced a SFHA that compares favorably with the effective SFHA. These boundaries provide an estimated SFHA in areas that have not been previously studied and therefore do not currently have an SFHA mapped. These results provide context for flood risk communication as part of the Discovery process, and should be verified through community work map meetings before being applied to a regulatory product.

A map showing the BLE results is included as Appendix A BLE Map.

4.2 Validation of Effective Zone A SFHA

The inventory of Zone A studies (640.8 miles) in the Hubbard watershed were classified in CNMS with validation status of "UNVERIFIED" (522.7 miles) or "VALID" (118.1 miles), and with status type of "BEING STUDIED." The following is a summary of the results of the CNMS validation assessment for the effective Zone A studies in the study area. Initial Assessment checks A1-A3 were evaluated for the CNMS inventory of Zone A studies.

4.2.1 Intial Assessment A1 – Significant Topography Update Check

This check involves determining whether a topographic data source is available that is significantly better than what was used for the effective Zone A modeling and mapping. No effective Zone A studies within this watershed used LiDAR data. The LiDAR sources utilized in this BLE study are considered significant improvements from the effective zone A topographic sources. Therefore, all reaches fail this check.

4.2.2 Initial Assessment A2 – Check for Significant Hydrology Changes

This check involves first determining if regression equations were used for the effective study. Next, it must be determined whether new regression equations have become available from the USGS since the date of the effective Zone A study. If newer regression equations exist for the area of interest, then an engineer must determine whether these regression equations would significantly affect the 1-percent annual chance flow.

No effective Zone A studies in this watershed used regression equations and, therefore, automatically pass this check.

4.2.3 Initial Assessment A3 – Check for Significant Development

This check involves using the National Urban Change Indicator (NUCI) dataset to assess increased urbanization in the watershed of the Zone A study. If the percentage of urban area within the HUC-12 watershed containing the effective Zone A study is 15% or more, and has increased by 50% or more since the effective analysis, the study would fail this check. Although the NUCI data provide year-to-year changes in urbanization, the NLCD also is needed to establish a baseline of urban land cover for this analysis. The check for significant development in this watershed was completed by evaluating percentage of urban change at the HUC-12 level.

All effective Zone A studies within the watershed are classified as rural and, therefore, pass this check.

All of the initial assessment results are shown in Table 10.

Table 10: Zone A Initial Assessment Results

Assessment Check	Pass / Fail	Notes
A1 – Topography	Fail	LiDAR sources available are considered significant improvements from the effective zone A topographic sources
A2 – Hydrology	Pass	Regression equations were not used
A3 – Development	Pass	Watershed does not meet urban threshold

4.2.4 Validation Check A4 – Check of Studies Backed by Technical Data

Zone A studies that pass all initial assessment checks described above may be categorized as “VALID” in the CNMS Inventory only if the effective Zone A study is supported by modeling or sound engineering judgment and all regulatory products are in agreement. If the effective Zone A study passes all initial assessment checks, but is not supported by modeling, or if the original engineering method used is unsupported or undocumented, a comparison of the BLE results and effective Zone A’s is performed.

No effective Zone A studies in this watershed are supported by technical data and, therefore, fail this check.

4.2.5 Validation Check A5 – Comparison of BLE and Effective Zone A

The BLE /effective Zone A comparison method leverages the existing Floodplain Boundary Standard (FBS) certification procedures described in FEMA SID 113, but with a slight modification. This modified FBS comparison approach uses the 1-percent plus and 1-percent minus flood profiles and horizontal and vertical tolerances described in FEMA’s Automated Engineering guidance document dated May 2016. For the comparison of BLE and effective Zone A in the Texas study area, the following vertical and horizontal tolerances were used to conduct the modified FBS procedure. One point was placed every 200 feet along the floodplain boundaries for comparison.

- Vertical Tolerance: +/- 5 feet (one-half contour interval of effective topographic source).
- Horizontal Tolerance: +/- 75 feet (standard horizontal tolerance for BLE comparison testing).

Comparison results for thse streams were grouped at the HUC-12 level and are summarized in Table 11 to better understand the general health of the HUC-12 watershed, but the validation check was performed at the stream level.

Streams where the percentage of passing FBS sample points is greater than or equal to 85% are marked as "Pass", otherwise marked as "Fail".

Table 11: BLE Comparison Results

HUC-12 Watershed		Total FBS points	Fail	Pass	%Pass	BLE Comparison Pass? (>85%)	Priority Score
Watershed Name	Watershed Number						
Hubbard Watershed	All Streams	30,355	7,932	22,423	74%	Fail	
Cordwood Creek-Deep Creek	120601050106	482	114	368	76%	Fail	9.1
Dry Branch-Hubbard Creek	120601050604	1,038	276	762	73%	Fail	19.3
East Fork Gunsolus Creek	120601050501	830	188	642	77%	Fail	18.1
East Sandy Creek	120601050403	951	129	822	86%	Pass	10.9
Flat Top-Deep Creek	120601050107	641	123	518	81%	Fail	15.4
Headwaters Hubbard Creek	120601050302	161	51	110	68%	Fail	20.3
Hog Branch-Big Sandy Creek	120601050408	1,473	287	1,186	81%	Fail	15.6
Hubbard Creek Lake-Big Sandy Creek	120601050409	763	73	690	90%	Pass	7.7
Hubbard Creek Lake-Hubbard Creek	120601050603	480	77	403	84%	Fail	8.3
Indian Creek-Hubbard Creek	120601050304	1,576	478	1,098	70%	Fail	19.3
Jenkins Creek	120601050301	504	361	143	28%	Fail	35.8
Live Oak Creek-Deep Creek	120601050104	51	1	50	98%	Pass	1.0
Long Run-Big Sandy Creek	120601050407	1,777	239	1,538	87%	Fail	10.8
Lower Battle Creek	120601050406	1,758	354	1,404	80%	Fail	13.6
Lower Gunsolus Creek	120601050504	1,405	323	1,082	77%	Fail	17.2
Lower Salt Prong Hubbard Creek	120601050204	1,124	410	714	64%	Fail	18.2
McDowell Creek-Hubbard Creek	120601050602	384	73	311	81%	Fail	11.2
Mexia Creek	120601050102	350	55	295	84%	Fail	9.3
Middle Battle Creek	120601050402	1,154	317	837	73%	Fail	22.0
Middle Gunsolus Creek	120601050503	1,538	231	1,307	85%	Pass	12.4
Middle Salt Prong Hubbard Creek	120601050203	1,303	521	782	60%	Fail	20.0
Newcomb Creek-Hubbard Creek	120601050601	1,216	356	860	71%	Fail	18.5
North Fork Salt Prong Hubbard Creek	120601050202	996	295	701	70%	Fail	16.2
Pecan Creek	120601050405	1,601	267	1,334	83%	Fail	13.3
Post Oak Creek	120601050105	328	141	187	57%	Fail	34.4
Reynolds Creek	120601050303	812	589	223	27%	Fail	45.1
Sandy Creek	120601050404	2,442	862	1,580	65%	Fail	27.6
Upper Battle Creek	120601050401	165	25	140	85%	Pass	8.2

Table 11, continued: BLE Comparison Results

HUC-12 Watershed		Total FBS points	Fail	Pass	%Pass	BLE Comparison Pass? (>85%)	Priority Score
Watershed Name	Watershed Number						
Upper Battle Creek	120601050401	165	25	140	85%	Pass	8.2
Upper Gunsolus Creek	120601050502	2,437	468	1,969	81%	Fail	15.4
Upper Salt Prong Hubbard Creek	120601050201	590	246	344	58%	Fail	20.8
West Fork Brushy Creek-Brushy Creek	120601050101	25	2	23	92%	Pass	4.0

4.2.6 Validation Results

Based on the validation assessments and BLE comparison results described above, the CNMS inventory of Zone A studies in the Hubbard watershed has been updated as summarized in Table 12 and illustrated in Figure 12.

Table 12: Zone A Validation Results

Validation Status	Status Type	Total Miles
VALID	BEING STUDIED	118.1
UNVERIFIED	BEING STUDIED	522.7

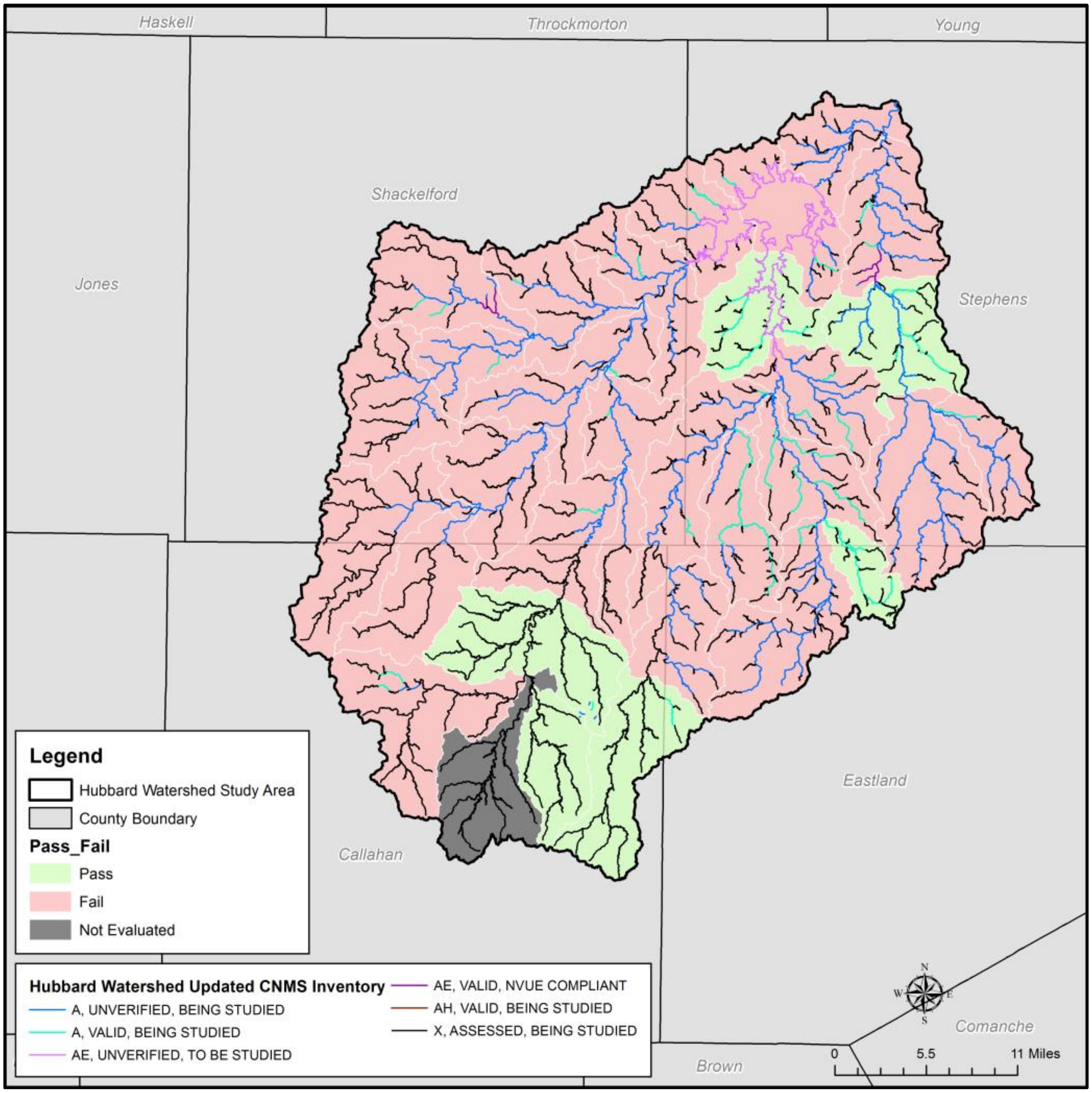

Figure 12: Hubbard Watershed CNMS Validation Results

An overall risk for each HUC-12 watershed was calculated using the National Flood Risk Percentages Dataset and its proportional area. The weighted risk was multiplied by the percentage of points in the watershed that failed the CNMS comparison to effective to determine the priority score. Figure 13 below shows the range of the HUC-12 priority scores which can be used to initiate discussions during the Discovery phase.

Reynolds Creek HUC-12 was determined to have the highest priority score and the most need while Live Oak Creek-Deep Creek HUC-12 had the lowest score.

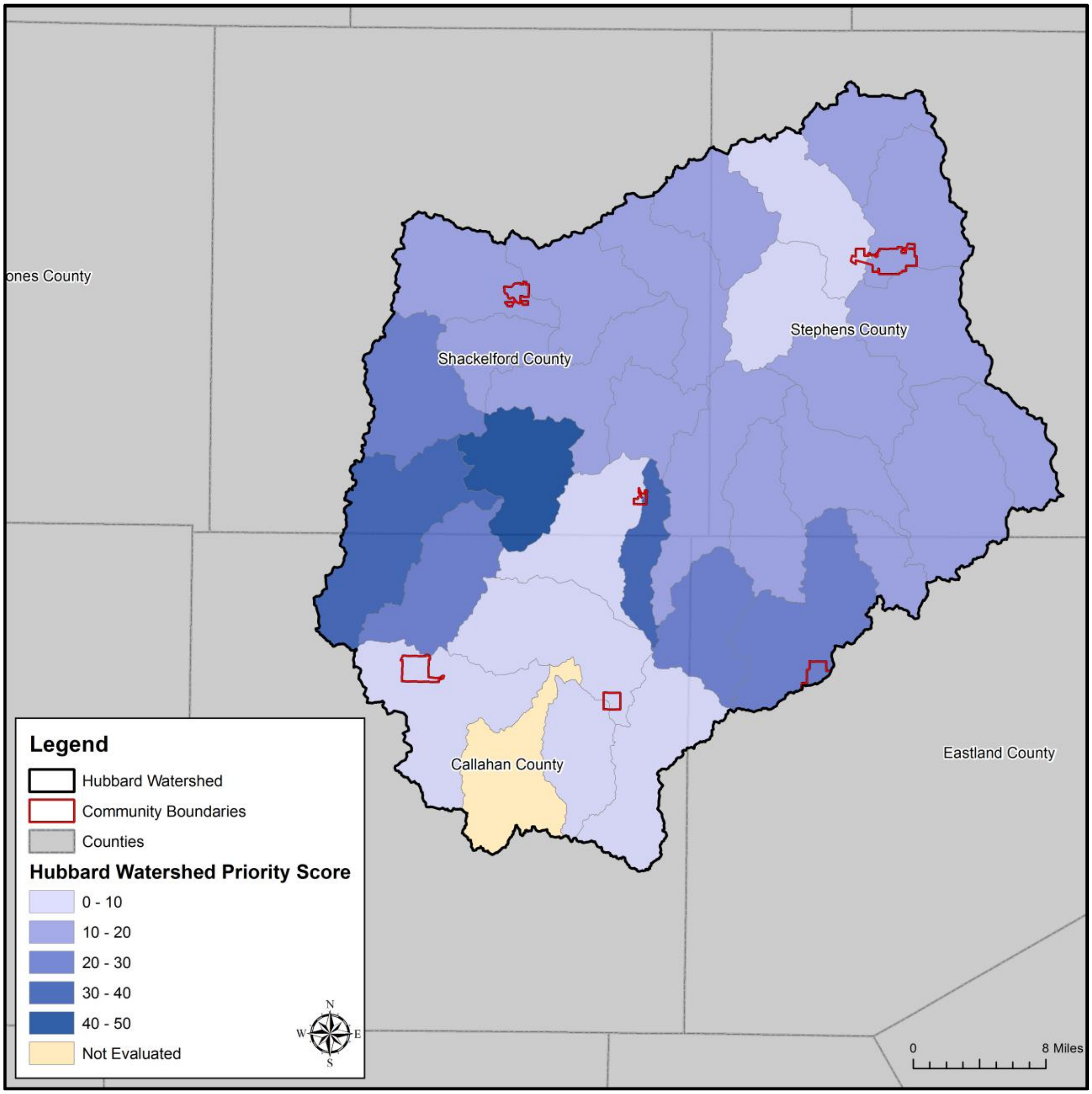

Figure 13: Ranking of Hubbard Watershed HUC-12s

4.3 Flood Risk Analysis

A flood risk analysis was performed for this project. The updated 1-percent annual chance depth grid was used to calculate the potential flood losses. The loss results are stored in the S_FRAC_AR spatial file within the FRD geodatabase. All results are reported in whole dollar values.

Hazus version 5.1 was used for the basic and refined loss analysis.

The losses are reported via census blocks. It is important to note that Hazus version 5.1 uses dasymetric census blocks. Dasymetric mapping removes undeveloped areas (such as areas covered by other bodies of water, wetlands, or forests) from the census blocks, changing their shape and reducing their size in these areas. For more information on dasymetric data visit FEMA's Media Library for the Hazus-MH Data Inventories: Dasymetric vs. Homogenous, or Hazus 3.0 Dasymetric Data Overview.

Hazus analysis was performed by county within the project watershed extents for each return period to ensure proper model processing. A summary of results for these counties for the 1-percent a.c.e. scenarios are shown in Table 13. Totals only reflect data for those census tracts/blocks included in the user's study region and will reflect the entire county only if all of the census blocks for that county/state were selected at the time of study region creation.

Table 13: Hazus 5.1 Results for 1-Percent-Annual-Chance (100 year) Scenario

County	Full Replacement – Total Loss	Dollar Exposure (Replacement Value) - Buildings	Dollar Exposure (Replacement Value) - Contents
Callahan	$41,059,000	$325,738,000	$195,401,000
Eastland	$18,436,000	$263,947,000	$170,904,000
Shackelford	$62,445,000	$333,091,000	$204,540,000
Stephens	$103,505,000	$877,063,000	$555,707,000
Total	$225,445,000	$1,799,839,000	$1,126,552,000

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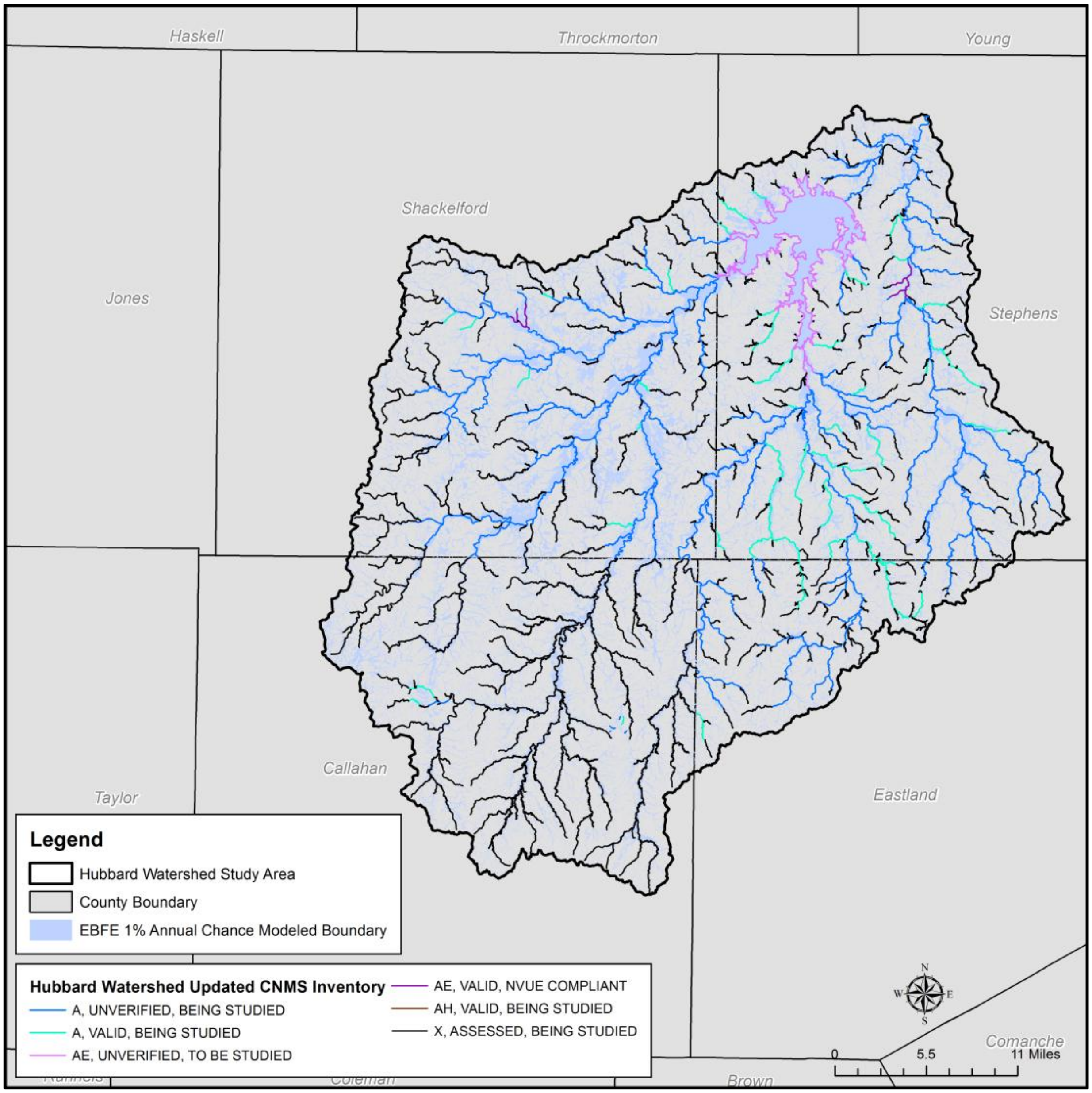
Appendix A BLE Map



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